Ozarks Environmental and Water Resources Institute
(OEWRI) Missouri State University (MSU)

Historical Rainfall Analysis for the Big Barren Creek Watershed, Southeast Missouri (1955-2015)

FINAL REPORT

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INTRODUCTION

Recent geomorphic instability in some headwater streams draining forest lands of the Missouri Ozarks has raised concerns among managers and other stakeholders. Increased flooding and excessive gravel deposition in stream channels can be related to a combination of climate-change, land management practices, and land use development. Further, it is not clear to what degree long-term adjustments to historical land clearing are still affecting watersheds today. The purpose of this study is to evaluate climate-change as one of the potential drivers of stream channel disturbance in Big Barren Creek in Mark Twain National Forest. Daily rainfall records are analyzed over the last 60 years to better understand if increased rainfall may contribute to increased stream flooding and channel instability. The specific objectives of this study are to: 1) create a daily rainfall data set for Big Barren Creek watershed for the years 1955 to 2015 using nearby gaging stations with the most complete records; 2) analyze the rainfall record to quantify annual and seasonal trends in rainfall amount and intensity; and 3) describe rainfall trends and their potential relationship to climate-change and watershed response. The results of this study indicate that both mean annual rainfall and frequency of high rainfall events has increased in the Big Barren Creek watershed over the past decade. Thus it is probable that climate factors have contributed to recent increased flooding and channel sediment problems in the watershed. Results of this study will be used to correlate rainfall trends with stream gage monitoring records, channel morphology, and historical aerial photography analysis of channel changes to evaluate the influence of other factors on headwater stream processes in Big Barren Creek watershed.

Background

National Climate Assessment 2014 predicts warming temperatures, longer dry periods, and higher frequency of intense rainfall events over the next 50 years in southeastern Missouri (Pryor et. al 2014). Historically, high magnitude rainfall events have accounted for a large portion of the annual rainfall in the region. Between 1971-2000, the top 10 wettest days of the year made up 36% to 42% of the total annual rainfall in southeast Missouri (NOAA 2013). However, the rainfall data from the Midwest suggests the magnitude of any given 1-day storm has not necessarily increased, but that high magnitude events have become more frequent (Villarini et. al 2013). These trends seem to suggest southeast Missouri will experience more extreme dry and wet periods where annual rainfall will be concentrated in higher magnitude events separated by longer dry periods.

The increase in high magnitude events can have implications flooding and widespread channel instability. Over the past 50 years, out-of-bank flood frequency has generally increased in the Midwest (Mallakpour and Villarini 2015) and continental United States (Jian et al. 2013). A temporal analysis of climate-channel morphology relationships during the Holocene indicate a strong link between flood regime and channel morphology in the Midwest and that bankfull floods can increase in peak discharge by 30% due to increases in mean annual temperature of 1-2 degrees Celsius and mean annual precipitation of 5 to 20% (Knox 2000). Hu et al. (2005) examined how climate-change and land cover changes could affect stream discharge in the Jacks Fork River basin. They find that peak flood flows could increase by 62-80% under scenarios that include forest clearing under wet climatic conditions. Indeed, the frequency of larger flood events has increased in recent years in Ozarks watersheds. Foreman (2014) found that the 100-year peak flood discharge has increased by greater than 30% over the last 30 years in 11 of 12 Ozark rivers examined with gaging records greater than 90 years. More frequent, high magnitude floods have the ability to cause widespread channel instability, excess gravel transport, and high bank erosion rates.

STUDY AREA

Big Barren Creek is a tributary of the Current River Basin (8-digit Hydrological Unit Code (HUC) #11010008) located in portions of Ripley, Oregon and Carter Counties in southeast Missouri (Figure 1). The Big Barren Creek watershed (190.6 km^2 (73.6 (mi^2)) is made up of two 12-digit HUCs, #110100080606 (Headwaters Big Barren Creek) and #110100080611 (Big Barren Creek). The watershed is located in the Salem Plateau physiographic subdivision of the Ozarks Highlands, which is underlain by flat, Paleozoic age sedimentary rock underlain by a structural dome that is part of a series uplifts about 150 m (492 ft) higher in elevation than the Mississippi Alluvial Plain located just to the southeast (Adamski et. al 1995). Southeast Missouri has a temperate climate with a mean annual temperature of 14.4º C (58º F) and mean annual precipitation around 112 cm (44 in) (Adamski et. al 1995). Land cover within the watershed is about 92% forested, with around 78% being National forest lands. The majority of the remainder is pasture and hay, along with small areas of developed open space.

METHODS

Daily rainfall records were obtained from the Midwestern Regional Climate Center's (MRCC) cli-MATE (MRCC's Application Tools Environment) (http://mrcc.isws.illinois.edu/CLIMATE/) database and data suitability for this project was based on proximity of the weather station to the Big Barren Creek watershed, the length of the period of record, and overall data completeness. Weather stations selected for analysis were located within 70 km (43.5 mi) of the Big Barren Creek watershed and had at least 60 years of rainfall records that were greater than 95% complete. Distance was calculated from each weather station to the geographic center of the watershed located near the junction of Carter County Road 169 and Forest Road 3145 (Latitude (DD) = 36.8549, Longitude (DD) = -91.0933). Daily rainfall was calculated for the Big Barren Creek watershed using the inverse distance weighted method using the following equations (Chen and Liu 2012):

$$R_p = \sum_{i=1}^{n} w_i R_i$$

$$w_i = \frac{1/d^2}{\sum_{i=1}^{n} 1/d^2}$$

where R_p is the unknown precipitation (cm) at the location of interest; R_i is the known precipitation (cm) at the weather stations; n is the number of stations used in the analysis; w_i is the weighting of each station; d_i is the distance (km) from each weather station. When daily rainfall records were not available for one of the stations for any particular length of time, the formula was altered to only use the records from the stations that had data for that timeframe.

After the rainfall record was modeled for the Big Barren Creek watershed, all daily rainfall records were assessed in 5-year intervals over the 60 year study period for daily rainfall amounts that exceeded 1%, 3%, 5%, 10%, and 25% of the time over that 5-year period. Additionally, the number of days within the 5-year period the daily rainfall exceeded 2.5 cm (1 in) and 7.5 cm (3 in) were counted. The same analysis was repeated by season in 5-year intervals. Seasonal data were divided into four datasets as follows: 1) fall between September 21st-December 20th; 2) winter from December 21st-March 20th; 3) spring between March 21st-June 20th; and 4) summer from June 21st-September 20th.

RESULTS

Weather Station Evaluation

A total of six weather stations were used to model the historical rainfall record for Big Barren Creek with distances to the center of the watershed ranging from 36.4 to 67.0 km (22.6 to 41.6 mi) from each distant gage (Table 1). The distribution of the gages generally surrounds Big Barren Creek with five of the rain gage sites located in Missouri and one in Arkansas (Figure 2). The stations located in Missouri are: Doniphan, West Plains, Summersville, Clearwater Dam, and Poplar Bluff. The station in Arkansas is located at Mammoth Spring. Weather station start dates ranged from 1893 for the Poplar Bluff station to 1948 for the West Plains station.

The daily precipitation record for each station was evaluated from August 1, 1955 to July 31, 2015 creating a maximum record length for each gage of 21,915 days in the 60 year period. All six stations had records of daily precipitation measurements for greater than 95% of the days possible. The number of daily records for the six stations used for this study ranged from 20,914 (95.4%) at the Summersville station to 21,655 (98.8%) at Doniphan (Table 2). Days with measurements of zero or trace rainfall depths of 0 to 0.13 cm (0-0.05 in) ranged from 76.8 to 81.3% of the time for the six stations. The distribution of days with rainfall depths greater than 0.13 cm (0.05 in) ranged in frequency among the six gages as follows: (i) 0.13 to 1.3 cm (0.05-0.5 in) from 9.9 to 14.8% of the time; (ii) 1.3 to 2.5 cm (0.5-1.0 in) from 4.7 to 5.2%; (iii) 2.5 to 7.5 cm (1.0-3.0 in) from 3.3 to 3.7%; and (iv) greater than 7.5 cm (3.0 in) occurred ≤0.3% of the time.

Missing Station Assessment

The distribution of missing rain depth values was examined further to evaluate their potential influence on the calculated rainfall record for Big Barren Creek. The distance-weighting method is used to calculate an average rainfall value for each day by the spatial averaging of daily record from each of the six gages. However, if rainfall records are missing from one or more of the gages on that particular day, the weighted average is therefore based on less than six gages. An evaluation of the frequency of missing values and the completeness of the records for the same day at all six stations shows that there was at least one station missing data 3,839 days (17.5%) over the 60 year period, but the majority of the missing data occurs during periods of no rainfall or very low rainfall. Over the 3,839 days with at least one missing station in the six gage dataset, 91.5% of the time had one missing station, 8.0% of the time there were 2 missing stations, and 0.5% of the time there were 3 missing stations (Table 3). When the average daily rainfall totals of the remaining stations are classified into rainfall categories for the days with at least one missing stations, the break down is similar to the percentage of time daily rainfall records from each station fall into those same categories. Therefore, the frequency distribution of missing values are representative of the distribution of rainfall depths within the complete record. Infrequent, extreme rainfall days were also affected in an unbiased manner. For example, for extreme daily totals greater than 7.5 cm (3 in), one station had missing data four times over the entire record and at no time was there an event greater than 7.5 cm (3 in) recorded at other stations when there were two or more stations missing data. This suggests missing data will have little effect on the accuracy of the estimates for the Big Barren Creek watershed.

Annual Rainfall Record Analysis

Annual rainfall totals from the Big Barren Creek watershed show large fluctuations in annual rainfall total with more extended cycles of wet and dry periods at the beginning and the end of the 60 year study period and have increased over the last decade. The mean annual rainfall at Big Barren Creek from 1956-2014 was estimated to be 119.8 cm (47.2 in) (Figure 3). Annual rainfall totals were compared to the mean to look at yearly departure from the long-term average. Very wet years occurred in 1957, 1973, 1982, and 2011 where rainfall was greater than 40 cm (15.7 in) higher than the long-term average. In contrast, 1963, 1971, 1976, 1980, and 2012 were very dry with annual rainfall totals greater than 30 cm (11.8 in) below the long-term average. Overall, rainfall is increasing on average 0.22 cm (0.09 in) every year over the last 60 years as indicated by linear regression of total annual rainfall over a calendar year (Figure 3). An extended dry period lasting from about 1959-1973 was followed by several years of oscillating wet and dry periods over shorter (4-8 years) periods from 1974-2005. However, since 2005 there has been an extended wet period even with two very dry years in 2010 and 2012. Over the last 10 years (2005-2014), total annual rainfall has increased 7% over the previous 20 years (1985-2004). These data suggest over the last 10 years the Big Barren Creek watershed has experienced relatively wet period compared to the previous 50 years. This pattern is not unique to southeast Missouri. Villarini et. al (2011) show the largest values of extreme rainfall events in the Midwest occur in eastern Kansas, Missouri, and Iowa. Additionally, previous studies of historical rainfall patterns have shown a steady increase in both total annual rainfall and the number of days rainfall has equaled or exceeded 5.1 cm (2 in) in the Midwest since the early 1900s (Angel and Huff 1997, Kunkel et. al 1999).

Text Highlight
*** Very wet years occurred in 1957, 1973, 1982, and 2011 where rainfall was greater than 40 cm (15.7 in) higher than the long-term average. In contrast, 1963, 1971, 1976, 1980, and 2012 were very dry with annual rainfall totals greater than 30 cm (11.8 in) below the long-term average.**

Analysis of the 60 year rainfall record in 5-year intervals shows that larger rainfall events appear to be occurring more frequently and have higher magnitude over the last decade. Data show that rain depths with ≤10% exceedance have increased over the last decade while events at the 25% exceedance have been fairly constant over the last 60 years (Figure 4A). The largest increase in depth is in the 1% exceedance rainfall event indicating an increase in frequency of more extreme rainfall amounts. The 1% exceedance rainfall has increased 21% over the last decade (2005-2015) compared to the previous 20 years (1985-2005). When looking at the number of daily rainfall totals that were greater than 7.5 cm (3 in) over the last 60 years there were a total of 16 occurrences (Figure 4B). Of those 16 occurrences, daily rainfall totals only exceeded 7.5 cm (3 in) six times from 1955-2005, while exceeding that threshold 10 times from 2005-2015. Similar trends can be seen in the number of daily records that exceed 2.5 cm (1 in) over the same time period. From 1955-1995 the number of daily rainfall totals greater than 2.5 cm (1 in) varied from 45 to 52 days over a 5-year interval (Figure 4C). However, after the number of days greater than 2.5 cm (1 in) decreased to 40 days from 1995-2000, the frequency of greater than 2.5 cm (1 in) events increased to around 60 days from 2005-2015, about four more days per year on average.

Text Highlight
*** When looking at the number of daily rainfall totals that were greater than 7.5 cm (3 in) over the last 60 years there were a total of 16 occurrences (Figure 4B). Of those 16 occurrences, daily rainfall totals only exceeded 7.5 cm (3 in) six times from 1955-2005, while exceeding that threshold 10 times from 2005-2015.**

Seasonal Rainfall Analysis

Seasonal analysis of the entire 60 year record by season shows the highest rainfall totals tend to occur in the fall and spring. For the 1% exceedance daily rainfall total over the study period, the fall and spring were the highest suggesting the most extreme events occur in those two seasons (Figure 5A). For the 3-5% exceedance the summer is slightly higher than the spring and fall suggesting more large events occur then, but perhaps not the most extreme events. For the 10-25% exceedance the spring daily totals are the highest. Of the 16 daily rainfall totals that were greater than 7.5 cm (3 in) over the last 60 year, 11 occurred in the fall and spring and the fewest in summer (Figure 5B). Similarly, the most days where rainfall totals were greater than 2.5 cm (1 in) were greatest in the fall and spring and lowest in the summer (Figure 5C). Overall, higher rainfall is typically occurring during the spring and fall in the Big Barren Creek watershed compared to the winter and summer.

Seasonal analysis of daily rainfall totals in 5-year intervals suggests the increase in rainfall over the last decade is from higher totals in the spring, summer and winter since 2000 while fall has been more consistent over time. Daily rainfall in the 1-25% exceedance range increased from 1955-1980 and was fairly consistent since that time (Figure 6A). While there have been periods of higher daily rainfall totals during the winter in the past 60 years, the 1-5% exceedance rainfall totals have increased since the 1990s while 10-25% exceedance rainfall depths have stayed the same or decreased slightly (Figure 6B). For the spring, the 1-5% exceedance daily rainfall totals decreased from 1955-1980, stayed relatively low from 1980-2000 and then has increased from 2000-2015 suggesting higher spring daily rainfall had occurred in the past and is returning after a 20 year period of lower daily rainfall (Figure 6C). Similar to the spring, the summer daily rainfall from the 10-25% exceedance daily rainfall total has remained fairly constant over the last 60 years (Figure 6D). However, the 1-5% exceedance daily rainfall totals decreased from 1955-1980, stayed fairly consistent from 1980-2000, and started to get higher since 2000.

Text Highlight
*** Seasonal analysis of daily rainfall totals in 5-year intervals suggests the increase in rainfall over the last decade is from higher totals in the spring, summer and winter since 2000 while fall has been more consistent over time.**

Analysis of seasonal daily rainfall totals that are greater than 2.5 cm (1 in) shows high variability over time and that the number of days of rainfall above that level has increased over the last 15 years, but it is similar to other periods over the last 60 years. Evaluation of fall daily rainfall totals that are greater than 2.5 cm (1 in) in 5-year intervals shows that there was more variability from 1955-2000, while the number of days greater than 2.5 cm (1 in) has been consistent since 2000 (Figure 6A). Winter daily rainfalls greater than 2.5 cm (1 in) appear to be oscillating in 10 year intervals with 2000-2010 being decade of higher than normal days of greater than 2.5 cm (1 in) rainfall (Figure 6B). In general, the number of daily rainfall totals greater than 2.5 cm (1 in) in the spring decreased from 1955-1990, but increased substantially from 1990-2010 (Figure 6C). Similar to the spring, summer daily rainfall totals greater than 2.5 cm (1 in) decreased from 1955-1990 and increased from 1990-2010, but changes were less significant (Figure 6D). Overall, the seasonal pattern shows an increase in the number of days rainfall was greater than 2.5 cm (1 in) in the winter, spring, and summer since 1990, but these are not outside the range of rainfall amounts that have occurred in the last 60 years.

SUMMARY AND CONCLUSIONS

There are 5 main summary/conclusions points from this study:

1. **Six weather stations were chosen for this study to estimate daily rainfall for the Big Barren Creek watershed from 1955-2015 using the inverse distance**

weighted method. Six weather stations within 70 km (43.5 mi) of the Big Barren Creek watershed were selected for use in this study with at least a 60 year record of daily rainfall and that were greater than 95% complete. A daily rainfall series was calculated for the Big Barren Creek watershed using the inverse distance weighted method and adjusted for periods of time with 1-3 missing stations using as few as three stations to estimate the daily record.

2. **Annual rainfall totals from the Big Barren Creek watershed show fluctuations in annual rainfall totals, but there is an overall increase over the entire study period with a historically wet period over the last decade.** An extended dry period lasting from about 1959-1973 was followed by several years of oscillating wet and dry cycles over shorter periods (4-8 year) from 1974-2005. However, it has been relatively wet since 2005 even with two very dry years in 2010 and 2012. Over the last 10 years (2005-2014), total annual rainfall has increased about 7% over the previous 20 years (1985-2004). These data suggest over the last 10 years the Big Barren Creek watershed has experienced a relatively wet period compared to the previous 50 years.

3. **Analysis of the 60 year rainfall record in 5-year intervals shows that high magnitude rainfall events appear to be occurring more frequently over the last decade.** There were a total of 16 occurrences of daily rainfall totals that were greater than 7.5 cm (3 in) over the last 60 years. Of those 16 occurrences, daily rainfall totals only exceeded 7.5 cm (3 in) six times from 1955-2005 while exceeding that threshold 10 times from 2005-2015. Overall, the 1% exceedance rainfall has increased 21% over the last decade (2005-2015) compared to the previous 20 years (1985-2005).

4. **Seasonal analysis of the entire 60 year record by season shows the highest rainfall totals tend to occur in the fall and spring, but the frequency of high magnitude rainfall events seems to be increasing in winter, spring, and summer over the last decade.** Seasonal analysis of daily rainfall totals in 5-year intervals suggests the increase in rainfall over the last decade is from higher totals in the spring, summer and winter since 2000, while fall has been more consistent over time. Analysis of seasonal daily rainfall totals that are greater than 2.5 cm (1 in) shows high variability over time and that the number of days of rainfall above that level is increasing over the last 15 years, but it is similar to other periods over the last 60 years.

5. **Increased frequency of extreme rainfall events over the past decade may be causing more out-of-bank floods, geomorphic adjustments, and excess gravel deposition in stream channels.** This study finds that intense rainfall events have

increased in frequency over the past decade as shown in other studies in the Midwest. It is highly probable that more intense storms and climate change in general is contributing to the hydrologic problems observed in the Big Barren Creek watershed including the increased frequency of flooding. However, more research is needed to evaluate the effects of other geomorphic and anthropogenic factors before the relative contribution of increased rainfall on floods, stream stability, and sediment can be determined.

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TABLES

Table 1. Rainfall monitoring stations used for this study

Station Name	State	County	Latitude (DD)	Longitude (DD)	Elevation (m)	Period of Record Start Date	Distance from Big Barren Creek Watershed (km)
Doniphan	MO	Ripley	36.6206	-90.8125	88.1	4/1/1904	36.4
Clearwater Dam	MO	Wayne	37.1319	-90.7756	201.2	11/1/1946	43.0
Mammoth Spring	AR	Fulton	36.4947	-91.5350	153.0	4/26/1904	56.9
Summersville	MO	Shannon	37.1397	-91.6272	374.0	4/3/1940	57.3
Poplar Bluff	MO	Butler	36.7578	-90.4056	112.8	1/1/1893	61.9
West Plains	MO	Howell	36.7425	-91.8347	307.8	7/1/1948	67.0

Table 2. Summary of individual weather station rainfall records

Station Name	# of Records	% Complete	0-0.13 cm	%	0.13-1.3 cm	%	1.3-2.5 cm	%	2.5-7.5 cm	%	>7.5 cm	%
Doniphan	21,655	98.8	16,654	76.9	3,052	14.1	1,090	5.0	795	3.7	64	0.3
Clearwater Dam	21,081	96.2	16,186	76.8	3,121	14.8	1,017	4.8	703	3.3	54	0.3
Mammoth Spring	21,110	96.3	16,474	78.0	2,768	13.1	1,080	5.1	748	3.5	40	0.2
Summersville	20,914	95.4	17,002	81.3	2,079	9.9	1,095	5.2	696	3.3	42	0.2
Poplar Bluff	21,306	97.2	16,543	77.6	2,891	13.6	1,040	4.9	776	3.6	56	0.3
West Plains	21,244	96.9	16,441	77.4	3,038	14.3	1,005	4.7	702	3.3	58	0.3

Table 3. Missing rainfall records across a single day from all six stations

Average Rainfall Range	Days w/1 station missing	%	Days w/2 stations missing	%	Days w/3 stations missing	%	At least 1 days missing out of 21,915 days	%
0-0.13 cm	2,288	65.1	219	71.6	7	38.9	2,514	11.5
0.13-1.3 cm	890	25.3	61	19.9	10	55.6	961	4.4
1.3-2.5 cm	248	7.1	15	4.9	1	5.6	264	1.2
2.5-7.5 cm	85	2.4	11	3.6	0	0.0	96	0.4
>7.5 cm	4	0.1	0	0.0	0	0.0	4	0.02
Total	3,515	100	306	100	18	100	3,839	17.5
% of all possible days (21,915)	16.0%		1.4%		0.08%		17.5%	

FIGURES

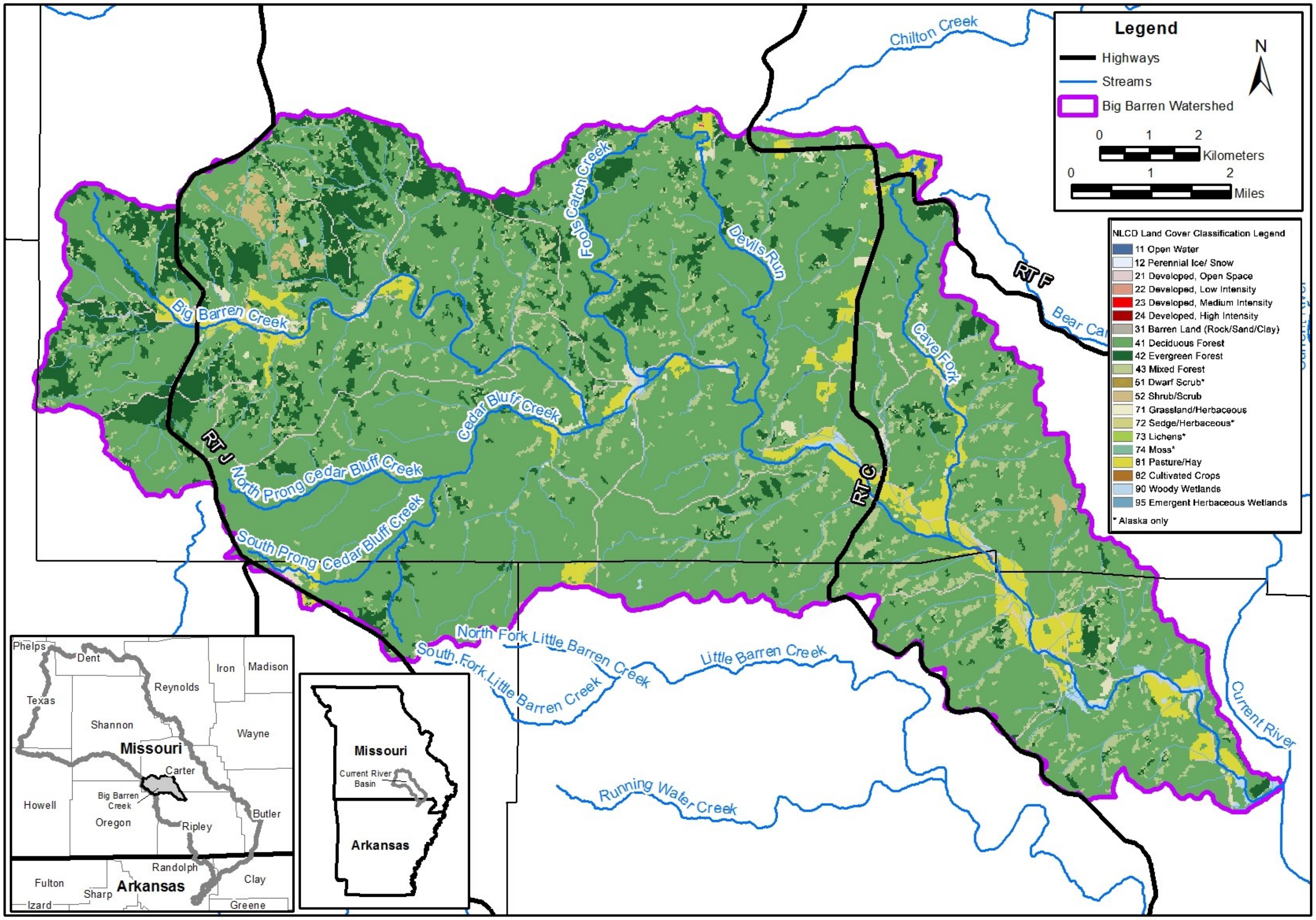

Figure 1. Location of the Big Barren Creek Watershed in Southeast Missouri.

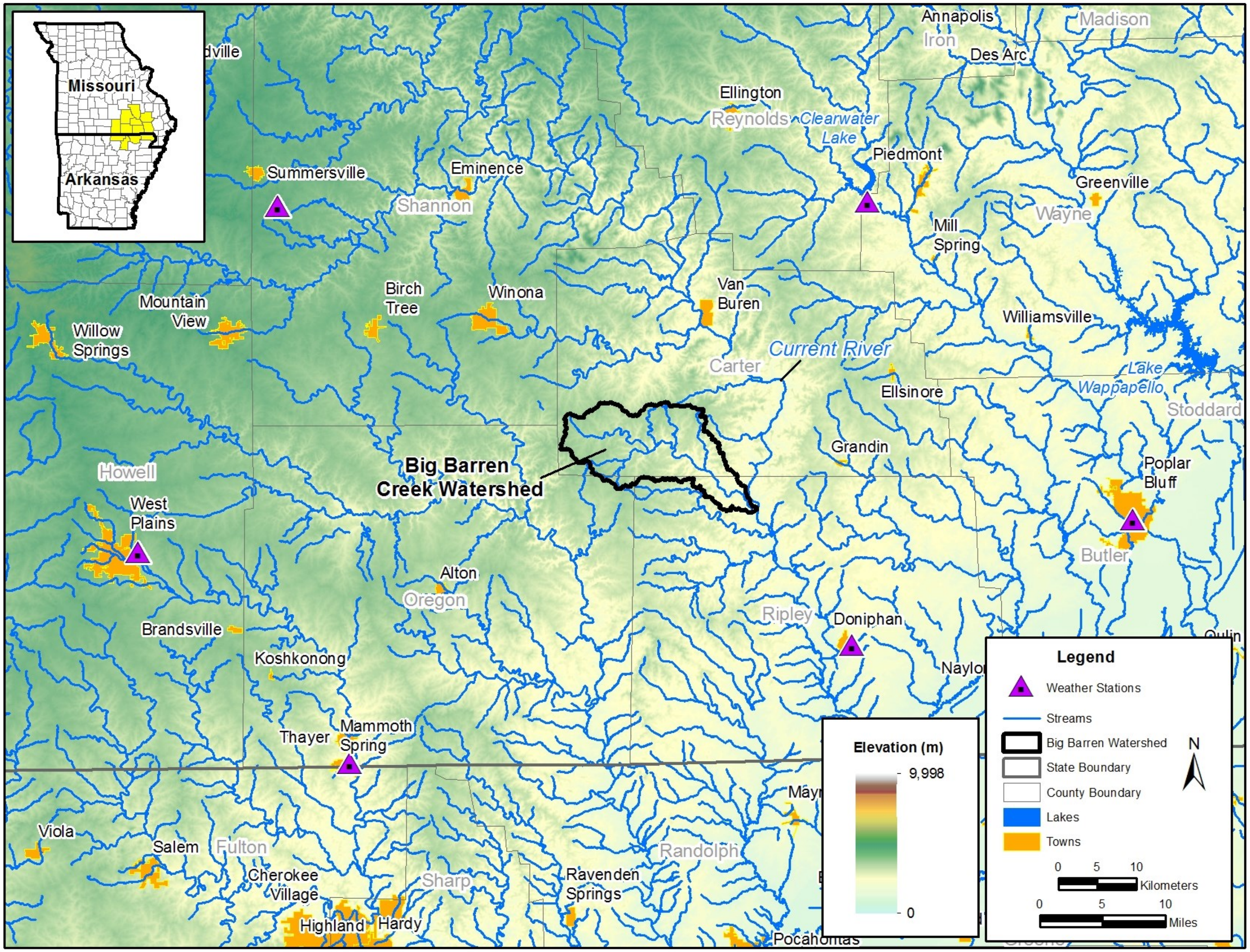

Figure 2. Locations of rainfall monitoring stations near the Big Barren Creek watershed.

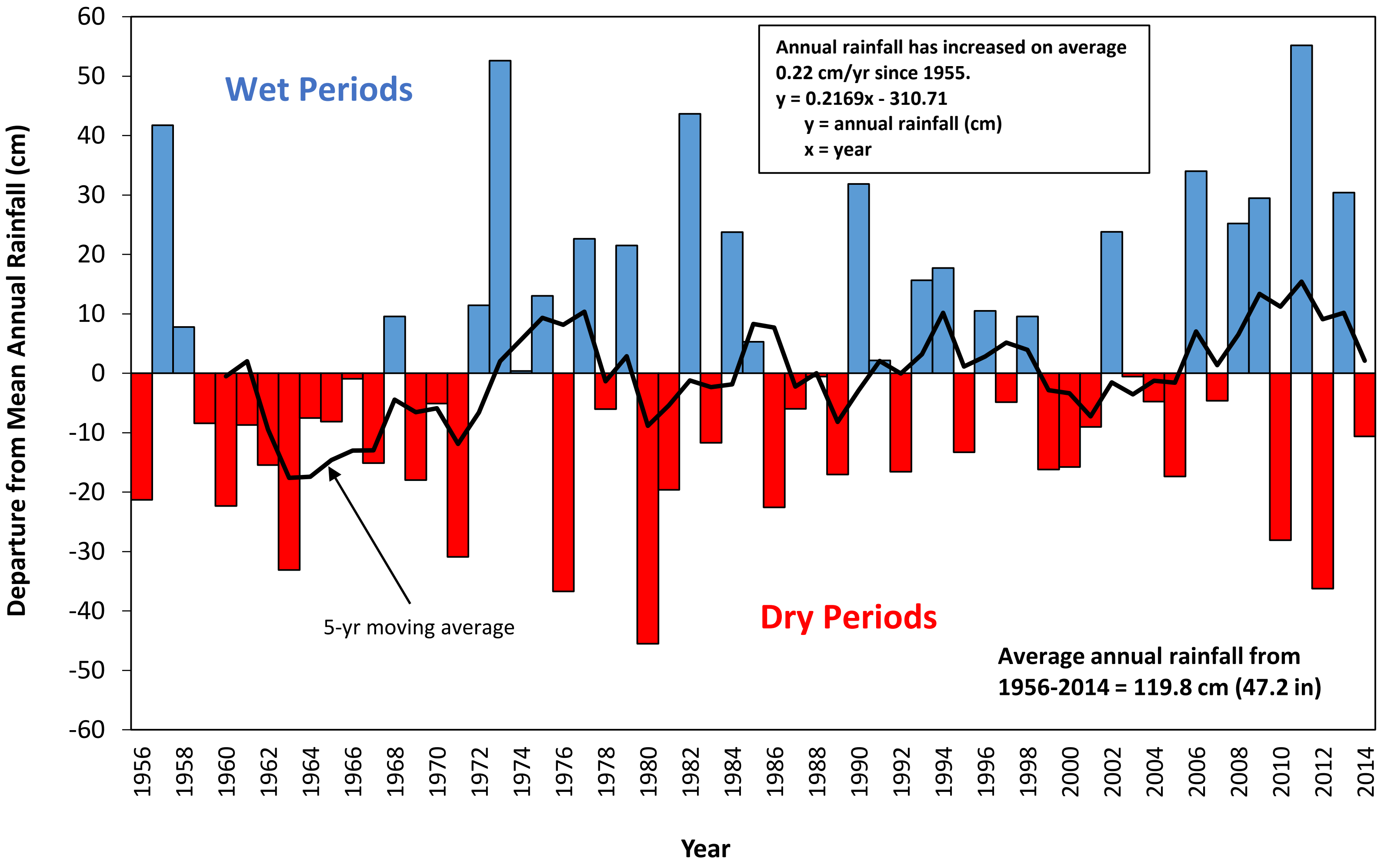

Figure 3. Annual rainfall departure from long-term average over the study period.

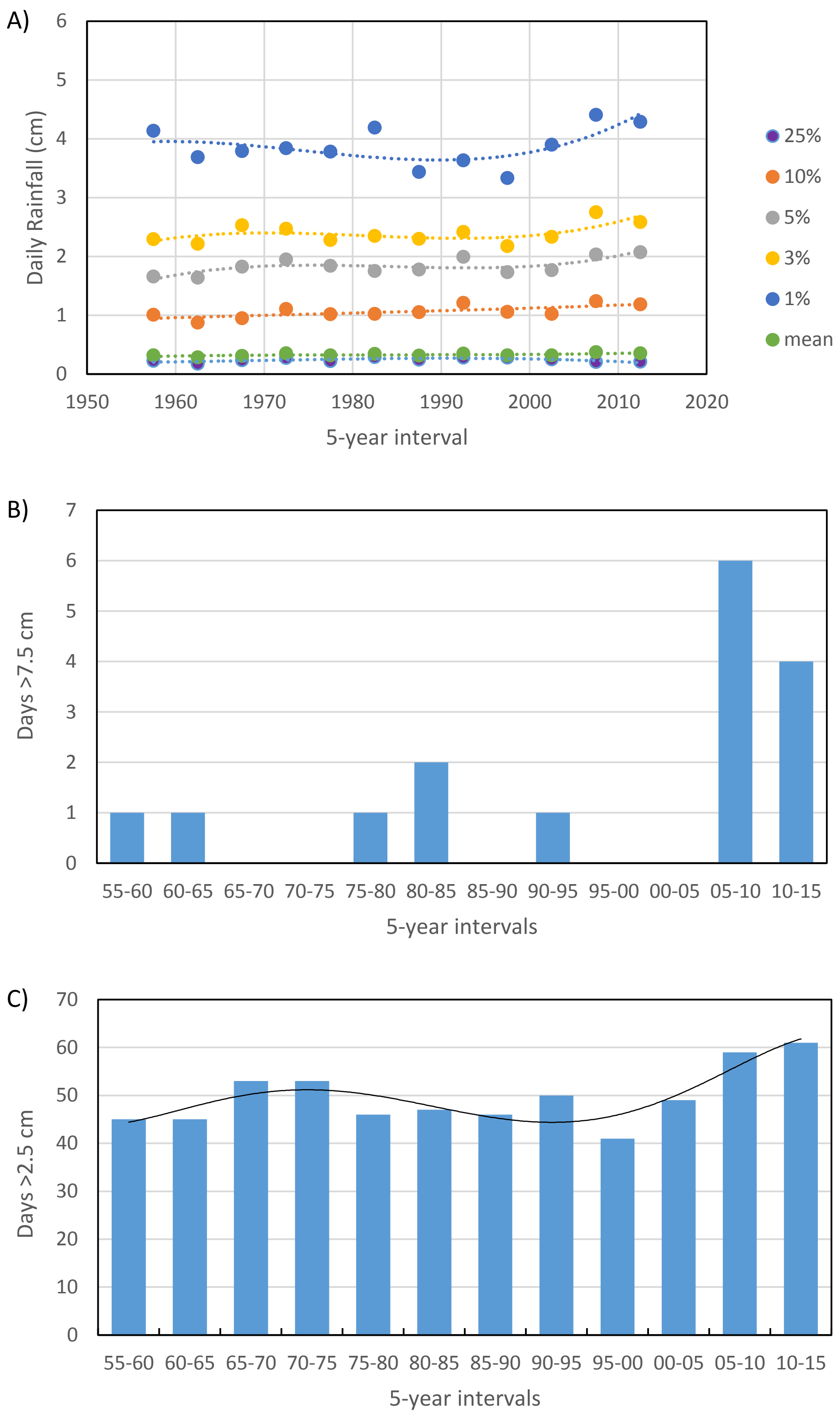

Figure 4. Daily rainfall records analyzed in 5-year intervals for A) percent exceedance and mean, B) days greater than 7.5 cm (3 in) rainfall and C) days greater than 2.5 cm (1 in) rainfall.

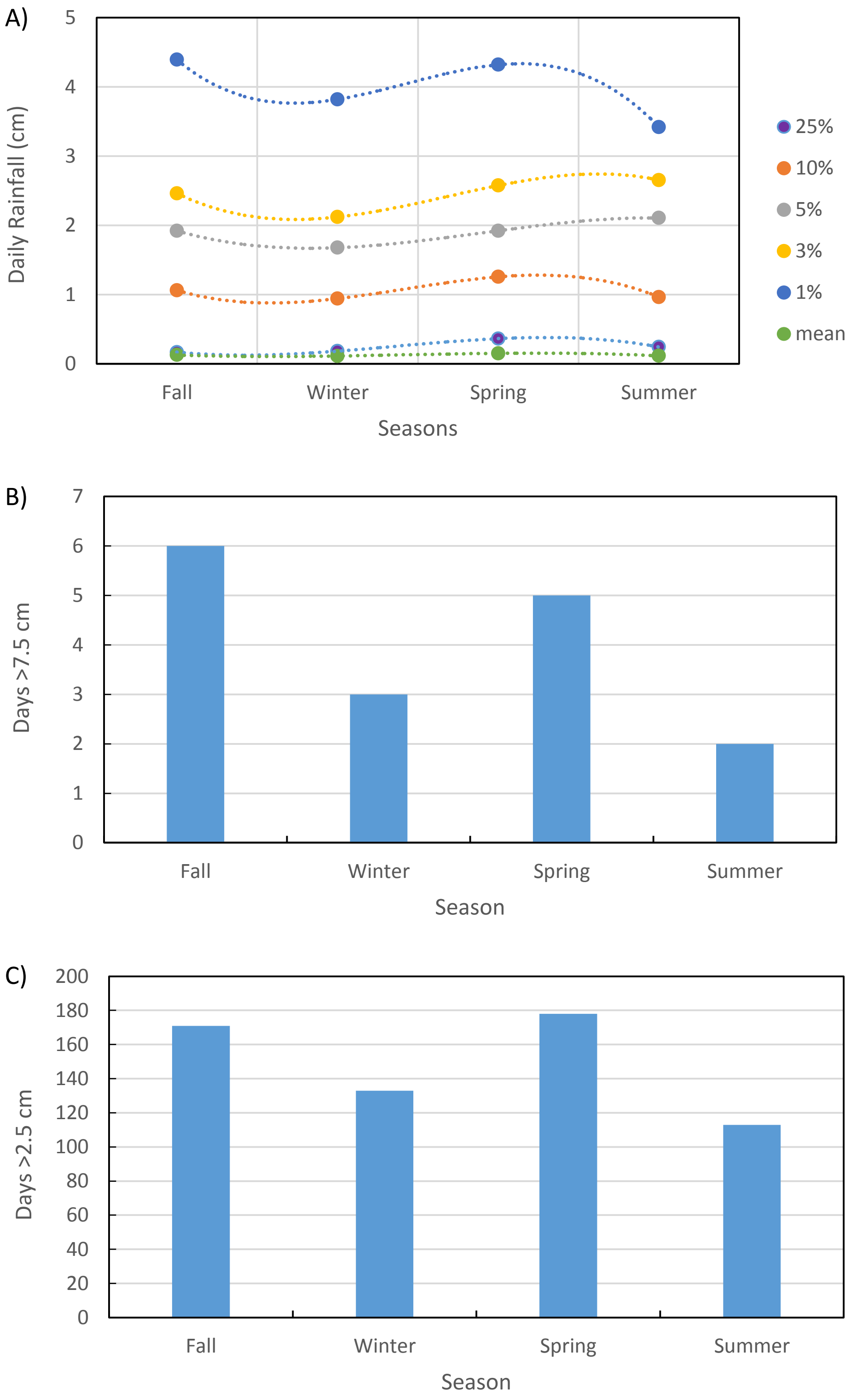

Figure 5. Seasonal rainfall analysis for Big Barren Creek watershed for the entire 60 year record for A) percent exceedance, B) days greater than 7.5 cm (3 in) rainfall and C) days greater than 2.5 cm (1 in) rainfall.

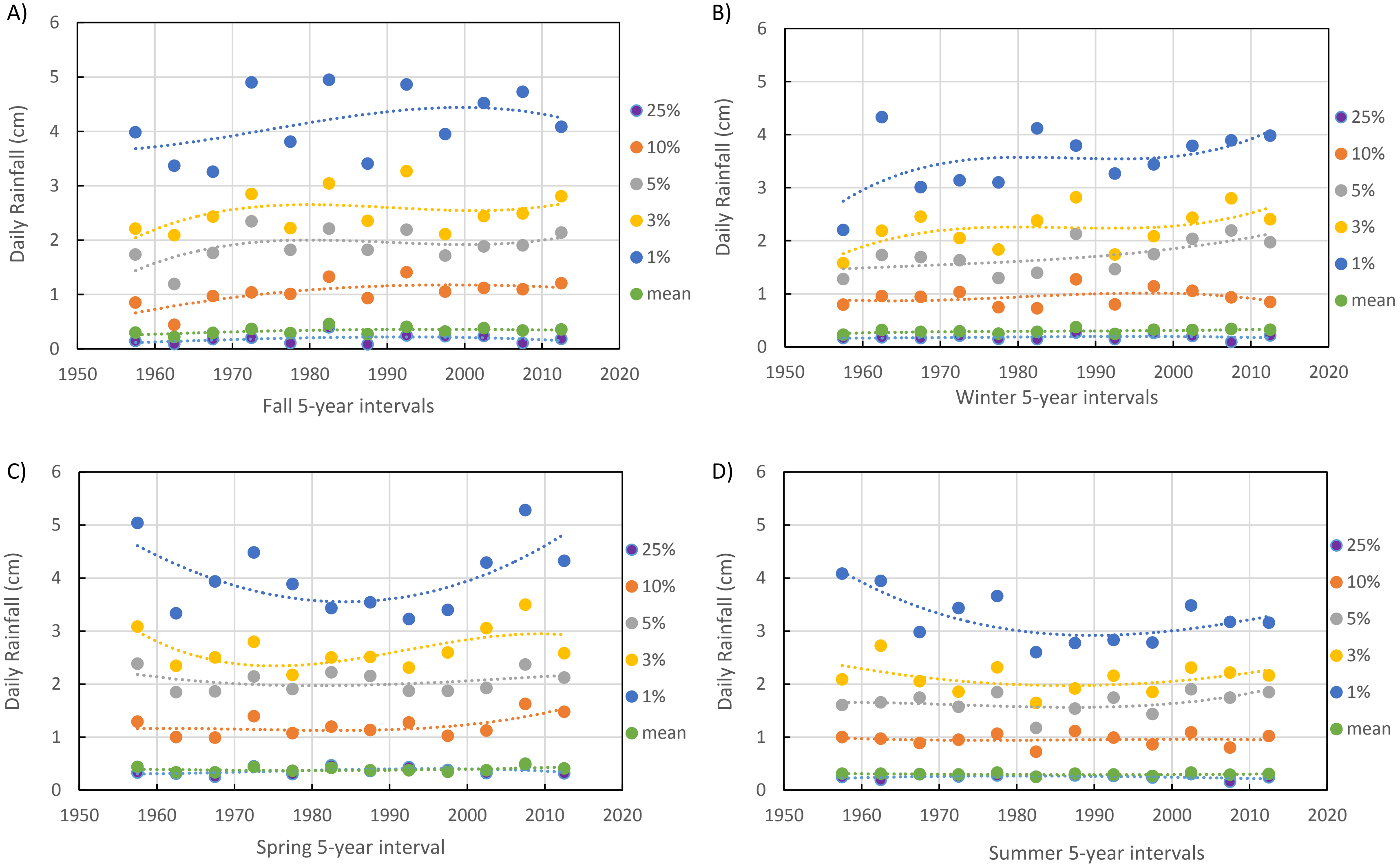

Figure 6. Seasonal analysis of daily rainfall percent exceedance in 5-year intervals for A) fall, B) winter, C) spring, and D) summer.

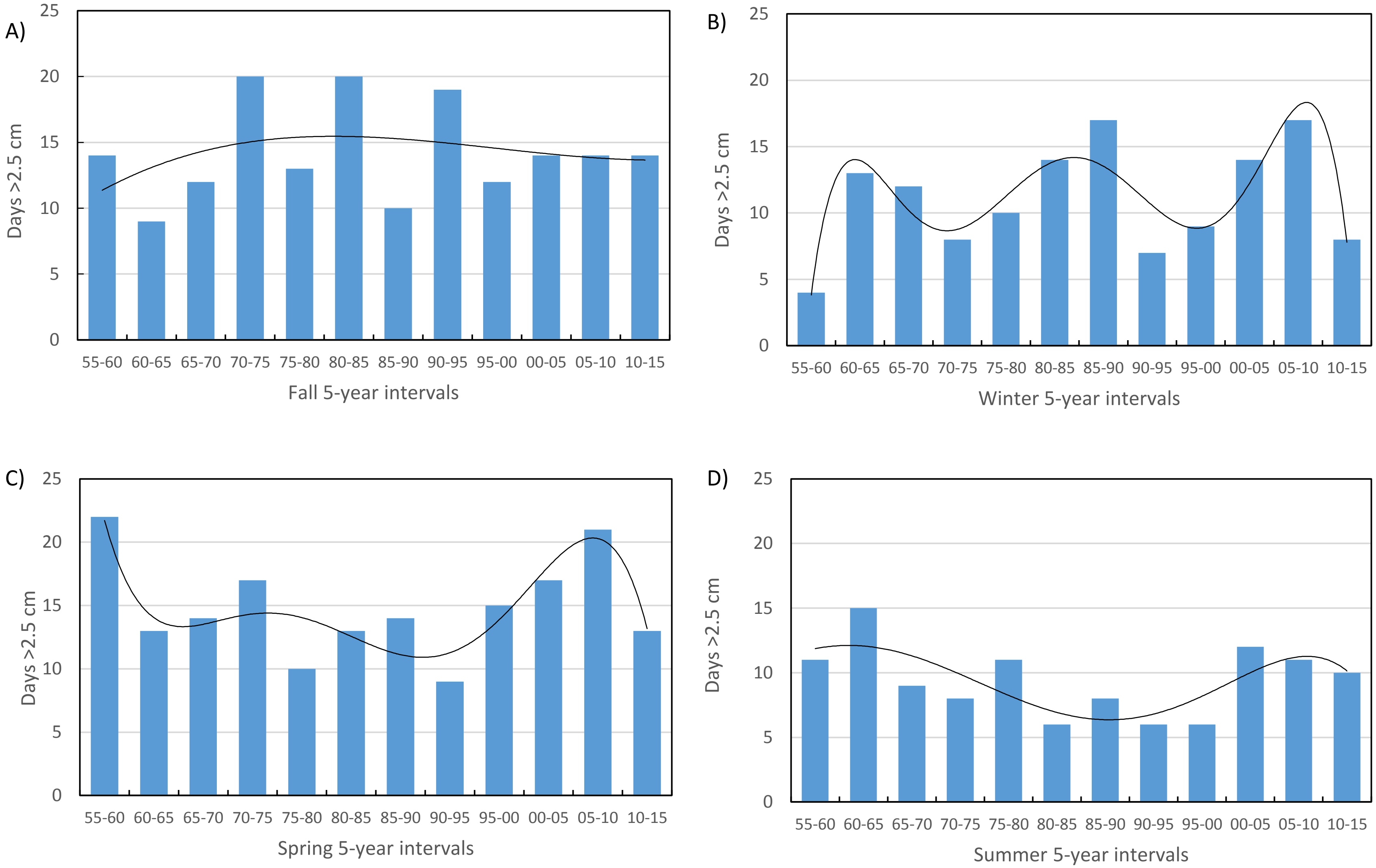

Figure 7. Number of days where daily rainfall was greater than 2.5 cm (1 in) analyzed in 5-year intervals for A) fall, B) winter, C) spring, and D) summer.